

# Single Event Transients in Voltage Regulators for FPGA Power Supply Applications

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## Introduction

As with other bipolar analog devices, voltage regulators are known to be sensitive to single event transients (SET). In typical applications, large output capacitors are used to provide noise immunity. Therefore, since SET amplitude and duration are generally small, they are often of secondary importance due to this capacitance filtering. In low voltage applications, however, even small SET are a concern. Over-voltages may cause destructive conditions. Under-voltages may cause functional interrupts and may also trigger electrical latchup conditions. In addition, internal protection circuits which are affected by load as well as internal thermal effects can also be triggered from heavy ions, causing dropouts or shutdown ranging from milliseconds to seconds [1].

In the case of FPGA power supplies applications, SETs are critical. For example, in the case of Actel FPGA RTAX family, core power supply voltage is 1.5V. Manufacturer specifies an absolute maximum rating of 1.6V and recommended operating conditions between 1.425V and 1.575V. Therefore, according to the manufacturer, any transient of amplitude greater than 75 mV can disrupt normal circuit functions, and overvoltages greater than 100 mV may damage the FPGA.

We tested five low dropout voltage regulators for SET sensitivity under a large range of circuit application conditions.

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## Tested Devices and Experimental Test Conditions

Tested devices are presented in Table 1. MS Kennedy and Satcon electronics parts are hybrid devices. The three first devices are radiation hard devices developed for the space market. TI devices are commercial parts. All parts have internal protection circuitries for thermal and over current effects. All devices were tested for a 3.3V input voltage and a 1.5V output voltage.

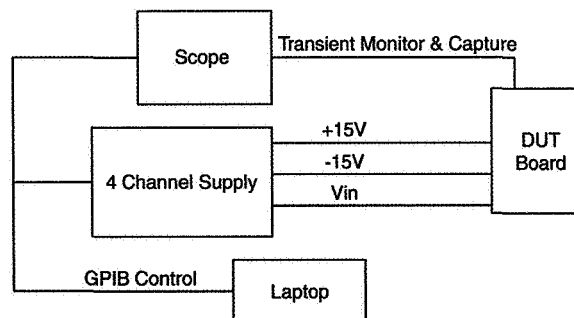
**Table 1: Tested devices.**

Type	Manufacturer	Output Voltage (V)	Output Current (A)
RHFL4913	ST Microelectronics	adjustable	3
MSK5900	MS Kennedy	adjustable	4
SAT8605R	SatCon Electronics	1.5V	3
TPS76701	Texas Instruments	adjustable	1
TPS73601	Texas Instruments	adjustable	0.4

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Devices under test (DUT) were tested under different load conditions. Test circuit is shown in Figure 1. It contains a power supply for the input voltage, an electronic load for drawing current, and a digital scope for capturing any output anomalies. Once the output is present and the load conditions are set, the digital scope is set to trigger on voltages that are above or below a predetermined threshold of 75 mV. Note that transients smaller than 75 mV may have occurred, but were not recorded.



**Figure 1: Overall test block diagram.**

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STM and MS Kennedy devices were tested at the Texas A&M University Cyclotron (TAMU) with a 15 MeV/u beam. The three other devices were tested at Lawrence Berkeley National Laboratory Cyclotron (LBNL) with a 10 MeV/u beam. Table 2 shows the characteristics of ions used for these tests.

**Table 2: Heavy ion test facilities and test heavy ions.**

Facility	Ion	Surface Linear Energy Transfer (LET) in Si at Normal Incidence (MeV·cm <sup>2</sup> /mg)	Range in Si, $\mu$ m
TAMU	Ne	2.8	260
	Ar	8.6	180
	Cu	20.3	123
	Kr	28.8	122
	Xe	53.1	108
LBNL	O	2.2	227
	Ar	9.7	130
	Cu	21.3	110
	Kr	31.3	110
	Xe	58.7	97

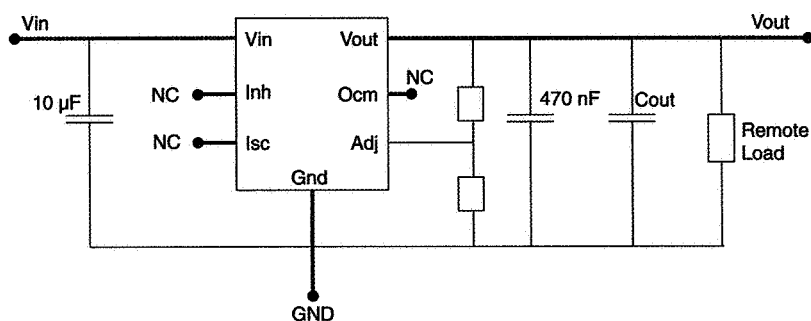
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## Test Results

### RHFL 4913

Figure 2 shows DUT bias condition during the test. Figure 3 shows the SET cross sections for an output capacitor value of 10  $\mu$ F. We can see that RHFL4913 SET susceptibility increases with output current.



**Figure 2: RHFL4913 bias conditions.**

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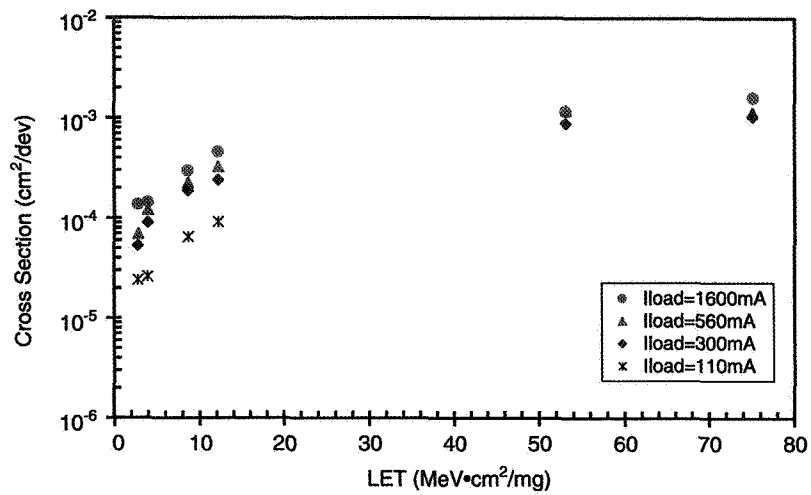


Figure 3: RHFL4913 SET cross-section curve.

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#### RHFL 4913 (Cont.)

Different transients were observed. Figure 4 shows the worst case transient waveforms. They were observed for the largest output current and the highest tested LET.

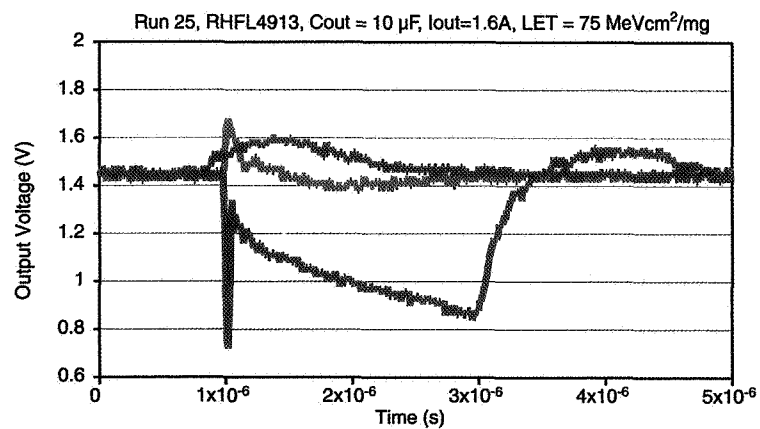


Figure 4: RHFL4913, worst case SETs.

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### MSK 5900

Figure 5 shows the SET cross sections for a 44  $\mu\text{F}$  output capacitor. We can see that MSK5900 is significantly less sensitive to SET than RHFL4913. MSK5900 susceptibility decreases with increasing output current. Part is not sensitive for output current larger than 500 mA.

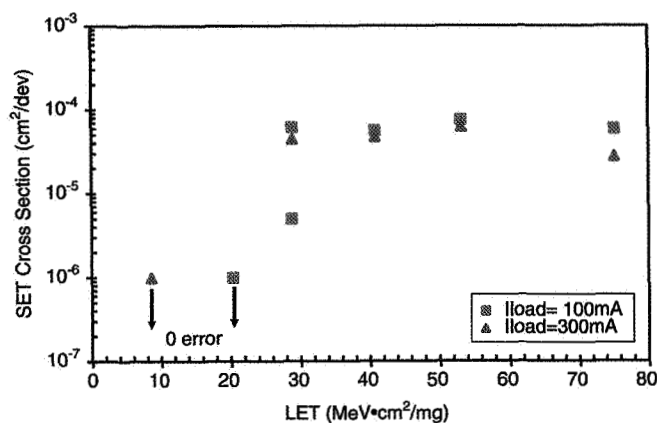


Figure 5: MSK5900 SET cross-section curve.

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Only one transient waveform was observed. Figure 6 shows typical transients. Maximum SET amplitude is 200 mV. Worst case transient duration is 4  $\mu\text{s}$ .

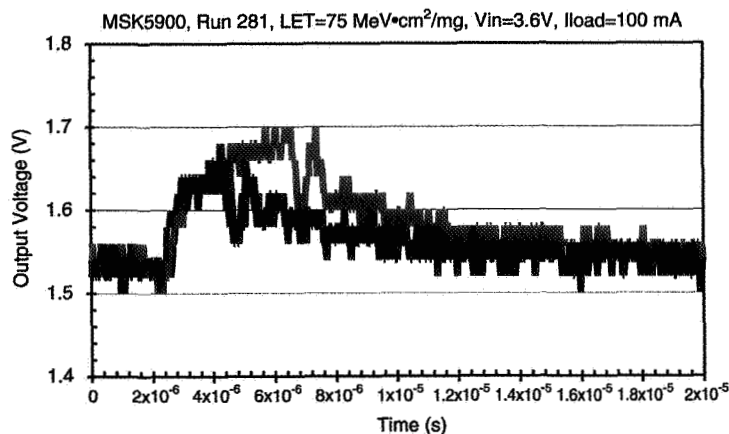


Figure 6: MSK5900 typical SET.

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### SAT8605R

Figure 7 shows the SET cross sections for 1000  $\mu\text{F}$  output capacitor. We did not observe a significant effect of output current on SAT8605R sensitivity. The SAT8605R is not sensitive for an output current lower than 100 mA.

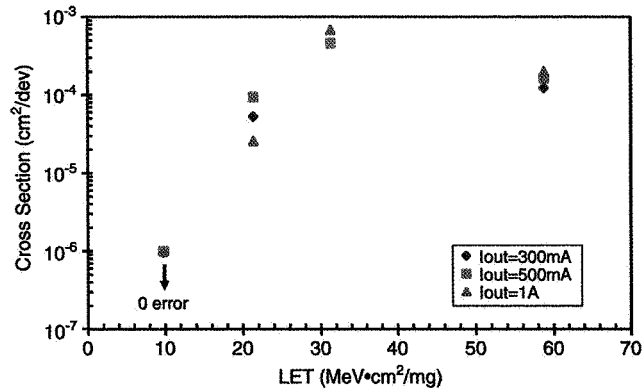


Figure 7: SAT8605R, SET cross-section.

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Only one transient waveform was observed. Figure 8 shows typical transients. Maximum SET amplitude is 450 mV. Worst case transient duration is 6  $\mu\text{s}$ .

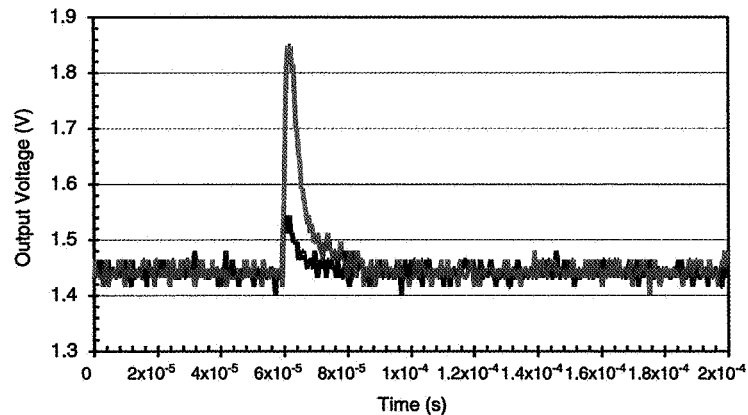


Figure 8: SAT8605R, typical SET.

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### TPS76701

Figure 9 shows the SET cross sections for a 10  $\mu\text{F}$  output capacitor. We can't see a significant effect of output current on device SET sensitivity. However, for high output current values, heavy ions trigger device internal protection circuitries causing circuit disruption effects.

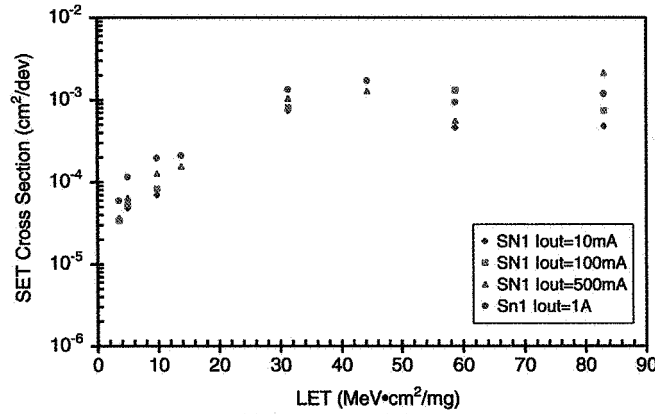


Figure 9: TPS76701 SET cross section.

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Figure 10 shows worst case SET. Device output goes down from 1.5V to 0V. In some cases protection circuitries are triggered and the device output if off for several milliseconds. About 20% of SET are long duration transients.

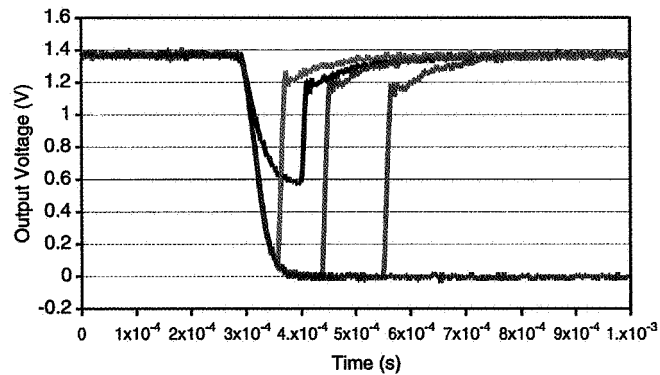


Figure 10: TPS76701 SET waveforms.

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### TPS73601

Figure 11 shows the SET cross sections for a 10  $\mu$ F output capacitor. SET sensitivity is higher for high output current values. SET sensitivity is negligible for 10 mA output current. As for TPS76701, for high output currents (> 100 mA), heavy ions again trigger device internal protection circuitries.

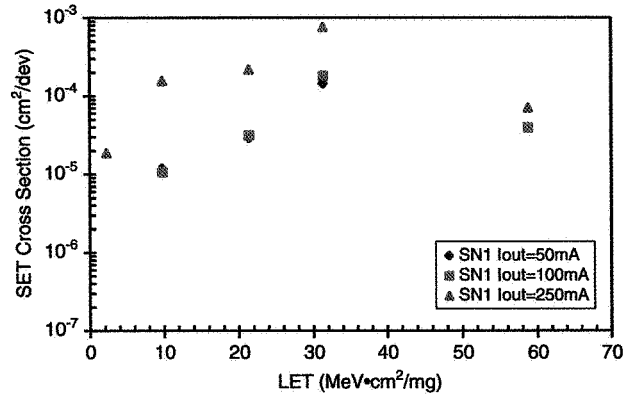


Figure 11: TPS73601 SET cross section curves.

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Figure 12 shows the worst case transients. Device is shutdown for up to 100 ms. All SET are long duration transients.

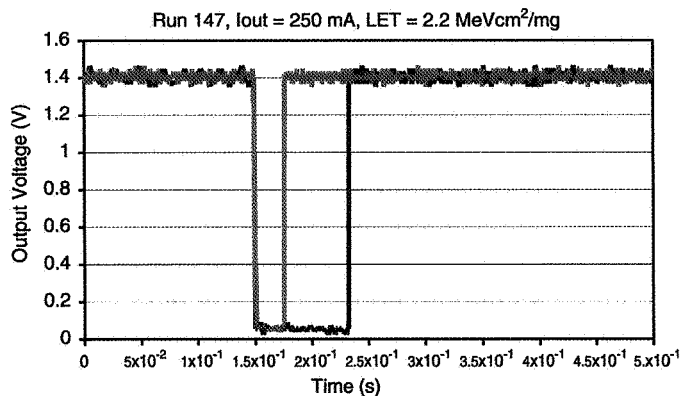


Figure 12: TPS73601 worst case SETs.

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## SET Mitigation

Data presented here shows that low voltage regulators are sensitive even though a large output capacitor is present at the device output. Increasing the output capacitor may be a way to mitigate SET. However, the low output impedance and high current capability of the regulator may overcome the expected filtering effect of bypass capacitors [1]. This can be seen in Figure 13 that shows RHFL4913 SET cross sections measured for 10  $\mu\text{F}$  and 660  $\mu\text{F}$  output capacitors. We can see that the measured SET cross-section are very close for the two values of output capacitor. We have tested RC filtering capabilities for RHFL4913 and MSK5900. Even though, all transients are not suppressed, the amplitude and duration of remaining transient is significantly reduced. The main drawback of a RC filter is the serial resistor that causes a voltage dropout. For a power supply application with a large dynamic range of output current, as it often the case for FPGA power supplies, voltage drop in the filter resistor can make power supply voltage go out of FPGA power supply specifications. To overcome this problem, we tested MSK5900 with a LC filter. This filter makes transients longer in duration, but the voltage amplitude of worst case transients was reduced from 200 mV to below 50 mV.

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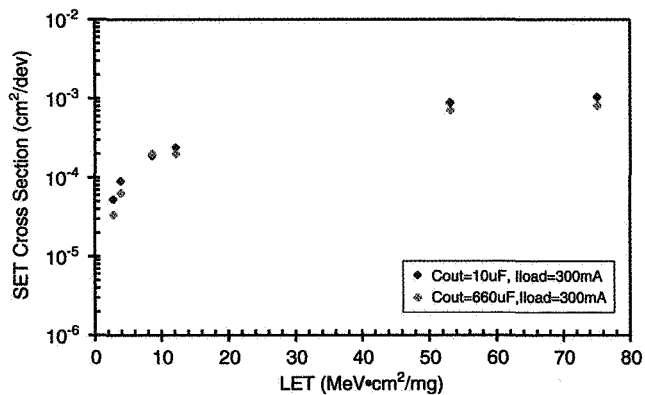


Figure 13: RHFL4913, SET cross-section for different output capacitor values.

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## Conclusions

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We have tested 5 different types of 1.5V voltage regulators for FPGA power supply applications. The five voltage regulators show very different transient susceptibilities when exposed to heavy ion beams. And, for each device type, sensibilities vary significantly with load conditions. Even applications with high output capacitors values may show transient sensitivity because of voltage regulators low impedance and high output current capabilities. For critical applications like FPGA power supplies, it is therefore recommended to test the voltage regulators with SET mitigation considered in the application.

## Acknowledgements

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## References

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- [1] A. H. Johnston, T. F. Miyahira, F. Irom, and J. S. Laird, "Single Event transients in Voltage Regulators," to be published in IEEE Trans. Nuc. Sci., vol 53, n6, Dec. 06.